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Head Impact Biomechanics of Collegiate Football Players

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by

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Abstract and Key Terms

This research study focused on the descriptive head impact biomechanics of collegiate American football players. The purpose of this study was to determine if there were statistical differences in the frequency, peak linear acceleration, and peak rotational acceleration between player position and impact location on the helmet during practice sessions. There were 31 players from the University of Southern Mississippi's Division I football team that participated in the study. Participants were divided into four groups based on position: defensive skill, defensive line, offensive skill, and offensive line. The Head Impact Telemetry (HIT) System was incorporated with the Sideline Response System to wirelessly acquire and record head impact biomechanics. Median values and [Interquartile ranges] of 23.3 [16.4-36.1] g and 1047.2 [693.3-1547.8] rad/s^2 were found for this sample. Of the 8,555 impacts recorded during practice sessions, significantly more impacts occurred to the front of the helmet than any other location [χ^2 = 2710.886, p= 0.001]. More impacts were sustained by the defensive line and defensive skill players than expected [χ^2 = 1962.444, p=0.001]. Higher linear acceleration values were seen at the top of the helmet and by offensive and defensive line players. However, high rotational acceleration values were sustained at the front of the helmet. Although there was significant difference in the rotational acceleration values and player position, no between group differences were found in the follow up test. A relationship was seen between impact location and player position. This study found that despite the notable dangers, impacts to the top of the helmet still result in the highest linear acceleration. This research could lead to future studies such as determining the significance of participation type on the results and if the distribution of players in the group had any impact on the results.

Key terms: HIT System, Sideline Response System, impact biomechanics, linear acceleration, rotational acceleration

Dedication

This research is dedicated to my family who has shown me constant love and support throughout this process. I would not be here today without their guidance and encouragement for me to always do my best. I would not have been able to finish this without my faith, and I want to thank God for giving me my dedication for learning and His guidance in my life. I also want to dedicate this to Matt for being there this past year; he always reminded me to be proud of my work and that what I did mattered. His love and inspiration got me through the hard times and enabled me to keep going.

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I would like to thank the Southern Miss Athletics department for allowing us to implement this system on our team to continue to learn more. A special thanks to Patrick Stewart, Assistant Athletic Director and Equipment Operations and Zach Gatwood, Assistant Equipment Manager for assisting with all of the logistical aspects of the implementation and maintenance of the system.

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2. SRS- Sideline Response System
3. NOCSAE- National Operating Committee on Standards for Athletic Equipment
4. ATP- Adenosine Triphosphate

CHAPTER 1: INTRODUCTION

Concussions due to impacts in American football at all levels of participation have become a prevalent issue over the past decade. Guskiewicz et al. reported that of the 17,549 high school and college football players surveyed in 2000, 5.1% of them sustained at least one concussion.[1] Furthermore, the Centers for Disease Control and Prevention reported in 2003 that mild traumatic brain injury costs the nation $17 billion every year, but noted that this number likely underestimates the actual cost to the nation due to various factors.[2] While many advancements have been made relative to the recognition, diagnosis, treatment and management of concussions, there is still much to learn about the consequences of head impacts and the role of sport protective equipment in preventing brain concussion.

Often impacts that occur in football participation result in concussions; therefore it is important to study the biomechanical factors of the impacts to better understand an individual's risk for sustaining a concussion. In 2009, Broglio and colleagues studied a group of high school football players to categorize biomechanical factors of impacts based on session type, player position, and impact location.[3] They reported that defensive line players sustained impacts that resulted in greater linear acceleration than defensive skill and offensive line players.[3] In 2007, Mihalik and colleagues studied a group of Division I football players over a single season. This study reported that impacts to the top of the head occurred more frequently than those to the back or sides of the head. Mihalik also found that offensive linemen sustained the most impacts compared to other players.[4]

Purpose

The purpose of this research is to determine if there are differences between impact location on the helmet and player position with respect to impact frequency, peak linear acceleration, and peak rotational acceleration values collected from a helmet-based biomechanical monitoring system over a single season of American collegiate football practices.

Research Questions

RQ1: Is head impact frequency equally distributed across five pre-defined helmet impact locations (back, front, left side, right side, and top)?

RQ2: Is head impact frequency equally distributed across four pre-defined player positions (offensive line, offensive skill, defensive line, and defensive skill)?

RQ3: Is there a difference between impact locations on the helmet by peak linear acceleration?

RQ4: Is there a difference between player positions by peak linear acceleration?

RQ5: Is there a difference between impact locations on the helmet by peak rotational acceleration?

RQ6: Is there a difference between player positions by peak rotational acceleration?

RQ7: Is frequency of head impacts for player position independent from impact of location on the helmet?

Hypotheses

H_1: More impacts will occur to the top of the helmet than to any other locations.

H_2: More impacts will be sustained by the offensive line than any other player group.

H_3: Impacts to the top of the helmet will sustain the highest peak linear acceleration of all impact locations.

H_4: Impacts sustained by the offensive skill will have the highest peak linear acceleration.

H_5: Impacts sustained to the front of the helmet will sustain the highest peak rotational acceleration.

H_6: Impacts that are sustained by the defensive line will have the highest peak rotational acceleration.

H_7: Head impact frequency by player position is independent of impact location.

Significance of Research

In the report Sports Related Concussions in Youth: Improving the Science, Changing the Culture, Graham et al. referenced future improvements that can be made to enhance the knowledge of concussions and their effects. These suggestions call for a long-term, in-depth study of players participating in the HIT system to have a better understanding of the total, long-term effects recurrent head impacts have on players.[5] This would allow for more effective rule changes and treatment guidelines. Studies like this have been done on a smaller scale; however, these are unable to determine the long-term effects of the game on players and if other factors affect injuries. This report also calls for additional research to determine if multiple concurrent impacts and long-term exposure to these impacts leads to diseases such as Chronic Traumatic Encephalopathy (CTE). The overall significance of this research is to add to the base of knowledge in this area for researchers to conduct more in-depth and telling studies about the field, including using the system at the University of Southern Mississippi in the future.

Definition of Key Terms

1. Riddell Revolution® IQ HITS™ Helmet: The helmet players wear that includes an individual monitoring system to record all significant impacts. The helmet contains a MxEncoder which consists of 6 single-axis accelerometers arranged in a U shape, positioned between existing cushioning pads. When a participant experiences an impact to the helmet, MxEncoder transmits information including: impact location, magnitude, and duration to a sideline computer.[6]
2. Riddell® Sideline Response System (SRS™): A group of technology that receives and records head impacts in games or practices incurred by the Riddell Revolution® IQ HITS™ Helmet. The system receives impact data via an antenna (Sideline Controller) as an analog signal that is then converted to a digital signal and stored in proprietary software (Hit Analyzer) on a laptop computer. At the end of each session onboard data is transferred to a secured web-based storage cloud (Redzone).[7]
3. Redzone™: Propriety web-based software platform that allows the user to create sessions, manage the roster, and create player summary reports.[8]
4. Linear acceleration: the rate of change of an object's velocity that is moving in a straight line[9]
5. Rotational acceleration: the rate of change of angular velocity, i.e. the rate at which the rotational speed of a body changes across a given angle of rotation[10]
6. Degrees of Freedom: the number of independent movements (ranging from one to six) a rigid body can complete to include translational motion on, and rotation about, three independent axes (longitudinal, vertical, and frontal).[11]

CHAPTER 2: LITERATURE REVIEW

Concussion Epidemic

Previous research has shown concussions made up 6.8% of serious injuries in men's collegiate football.[12] It is estimated that 1.6-3.8 million sports related concussions are sustained each year.[13] Concussions in American football have become a serious concern over the past two decades, and have sparked an influx of research in the area. In 2003, the Centers for Disease Control and Prevention published a report for Congress discussing the vastness of this issue and the unreliability of the reported data due to underreporting of symptoms.[2] This report and a report by The National Academies in 2013 led to the conclusion that there is a need for better education, diagnostic tools, and baseline biomechanical knowledge of concussions.[2,5]

In a study done by Guskiewicz et al.[1], about 400 questionnaires were sent to athletic trainers that would be filled out when concussions and head injuries occurred during a season. Of the 17,000 players who participated in this study, about 5% of them were reported to have sustained at least one concussion during a single season.[1] These reports also spoke to the symptoms these players showed before or after diagnosis. Guskiewicz et al. found that 95% of individuals who sustained a concussion had some mental confusion, 67.5% of players reported dizziness, but only 8.9% of concussions resulted in loss of consciousness.[1] These and other similar findings have lead researchers to conclude that loss of consciousness cannot be used to determine whether or not a player sustained a concussion. Therefore, better diagnostic techniques than loss of consciousness are necessary for accurate diagnosis of concussions.

Physiology of Concussions

Concussions are a form of mild traumatic brain injury that are normally characterized by the symptoms produced; however, concussions are much more complex than just the visible signs and symptoms. When an individual incurs a concussive impact, neurons in the brain are mechanically stretched and twisted. This results in a spontaneous flux of ions across the neurons membranes as well as a release of neurotransmitters. The spontaneous release of neurotransmitters and ions leads to a positive feedback loop that results in abnormal levels of depolarization in the neurons. Furthermore, this positive feedback loop opens Ca^{2+} channels through which an excess of Ca^{2+} flows into the neurons causing further cellular damage. In response to the release of neurotransmitter and ions there is an attempt by the neurons to increase Adenosine Triphosphate (ATP: the main energy source of cells) production to restore the cell membrane to a homeostatic state. However, the ionic flux creates a mismatch between the need for ATP and the cells' ability to produce ATP. Eventually this process can lead to neuronal death[14]. Furthermore, the energy crisis can leave the brain even more vulnerable to injury from subsequent impacts.

Despite our understanding of the pathophysiology of concussion, clinicians still must rely upon secondary indicators of concussion. To improve the diagnostic and reporting of concussions, researchers must develop a biomarker to identify concussions. Graham, Rivara, Ford, and Mason call for biomarkers to identify if a person has a concussion and to create a standardized care plan for all teams.[5] This would eliminate any issues of underreporting due to a lack of knowledge. Although these markers have yet to be discovered, there is potential that one or more proteins within the brain could serve as a biomarker.[14] There is still much research to be done in this field of pathophysiology.

Underreporting

Although there seems to be a higher rate of diagnoses of concussions in collegiate players compared to high school players, many participants do not report their concussions.[15] For example, Delaney and colleagues, found that although 16.5% of the 328 football players admitted to sustaining one concussion during the 1998 season, 70.4% of players reported having symptoms of a concussion at some point in the season.[16] Such underreporting can place players at an unnecessary risk for injury. In other words, when a player continues to play after sustaining a potentially concussive impact, they increase their likelihood of serious injury because the brain has not had time to heal from the initial injury.[17] Broglio et al. notes the lack of player and coaching staff concussion education, and argues that education could decrease the rate of underreporting of concussions in players.[18]

Helmet Safety

Head impacts that cause concussions in football have been a topic of interest and bewilderment for the last two decades. As the need for understanding on the topic grew, so did the need for better safety equipment. While the evolution of the football helmet design caused a decrease in serious head injuries, the use of helmets in football has not correlated to a decrease in the number of concussions seen in players.[19, 1] Helmet use did not become mandated until the 1930s, and leather ones were still in use until the 1940s.[20] The evolution of the football helmet came about as the growing need for better safety measures arose as a result of the increase in head fractures and spinal cord injuries from sports participation.[21] But it was not until 1970 that the National Operating Committee on Standards for Athletic Equipment (NOCSAE) was formed to create better helmet standards. NOCSAE developed a standard impact test to determine a base, which allows for across the board helmet safety comparisons. While these safety measures have decreased the likelihood of a person sustaining one of these serious injuries, there has been little to no decrease in risk for sustaining a concussion in football.

Impact Biomechanics

The Head Impact Telemetry System technology (HITs; Simbex, Lebanon, NH) was used in the Sideline Response System to provide a real-time wireless data collection of all helmet impacts sustained by players using the system. Sensors were placed in the helmets and recorded the linear and rotational acceleration, frequency, and location of the hit on the helmet. The HIT System also records head impact exposure, which is a composite score that includes the frequency, location, and kinematics of any impact sustained.[22] One of the first studies to report on this system was Duma et al.in 2005. About 3,000 impacts were recorded during a single season and it was found that the average linear acceleration was 32 ± 25 g.[23] The importance of this study is that it was the first research to report data from the system, and has been a basis for comparison for more recent studies.

Since the technology has become available, the observance of high linear and rotational acceleration values of the head have aided clinicians in identifying potential concussions in football. Although most research only focuses on the effects of linear acceleration on concussions, it is now thought that both types of acceleration (linear and rotational) affect the risk of sustaining a head injury from an impact.[5] For example, Beckwith found a correlation between higher head kinematics, which included linear and rotational acceleration, and the likelihood of a player sustaining a concussion.[22] However, there is still more research that needs to be conducted to help determine a relation between severity of head impacts and rotational acceleration. This area is an opportunity for future research to determine if the rotational acceleration and the risk for concussion are correlated or if this relationship is isolated to Beckwith's study.

CHAPTER 3: METHODOLOGY

Participants

Thirty-one players from a southern NCAA Division I football team were equipped with Riddell® HITS IQ helmets for the 2016-2017 season. These collegiate aged players had a mean mass of 102 ± 19 kg and a height of 185 ± 7 cm. The sensor equipped helmets were used during games and practices to provide an array of data points. These players were broken up into four categories: offensive skill (n= 9 quarterback, tight ends, and running backs), offensive line (n= 4 offensive linemen and offensive tackle), defensive skill (n= 13 line backers and safety), and defensive line (n=5 defensive end and defensive linemen). Before participating in this research, all participants read and signed an informed consent document that was approved through the University's Institutional Review Board (Appendix A and B).

Instrumentation

The Head Impact Telemetry System (HITS: Simbex LLC, Lebanon, NH) is a wireless, real time recording device, located in the space between cushioning pads, that monitors the impacts sustained by players using the system. The HITS device is integrated with the Sideline Response System (SRS: Riddell Corp., Elyria, OH).[8] The SRS is composed of four main parts: the MxEncoder, the field case, the Sideline Controller, and the Alert System. The MxEncoder is a sensor array containing six single axis accelerometers and is

Figure 1MxEncoder

placed into the free space at the top of the helmet (Figure 1). The field case (Figure 2) holds the computer, which contains the software to create and monitor sessions, as well as analyze data recorded by the system. This case is set up on the sideline of the field, and can perform in the rain as long as the top of the case is closed. Two software programs are on the computer and used in this research. The first is RedZone which can create the roster, manage sessions, and create a player report. A session is the time in which the players are equipped with their helmets and participating in some activity such as a game or practice. Creating a session around this time frame allows for only impacts that occurred in a session to be recorded, eliminating the incidence of false readings. The second software, HIT Analyzer, is used on the field to record impacts in real time. The Sideline Controller (Figure 3) transmits impacts registered by the helmets to the HIT Analyzer Software for viewing and analysis. The Alert System (Figure 4) is used to communicate with the coaching staff when an impact occurs over a certain threshold. Each player can have a specific threshold based on their position and other factors determined by the staff. Any time an impact exceeds the set threshold, the pager goes off alerting the staff of a potential dangerous hit.[8]

Figure 2 Field Case

Figure 3 Sideline Controller

Figure 4 Alert Pager

The HIT Analyzer software divides the outer surface of the helmet into 5 regions: front, top, back, left side, and right side. Broglio et al.[3] created a depiction of the separation of impact location which served as the inspiration for Figure 5 in this research. Impacts at 60˚ above the head's center of mass are categorized as top, and impacts below 60˚ of the center of mass are separated into back, front, right side, or left side as determined by the azimuth locations as diagramed in Figure 5. The HIT Analyzer uses the sensor locations within the helmet to determine the location the hit occurred.[8] Impacts sustained that are below 10 g were not be registered by the HIT system. **Validity evidence.** Previously, the HIT system was validated with impacts performed on a Hybrid III headform. There was some variation in impact location between the two systems, and underreporting of rotational acceleration by the HIT System by about 6.1%. [24] Other studies investigating the accuracy and validity of the HIT system have found similar results.[24] [25]

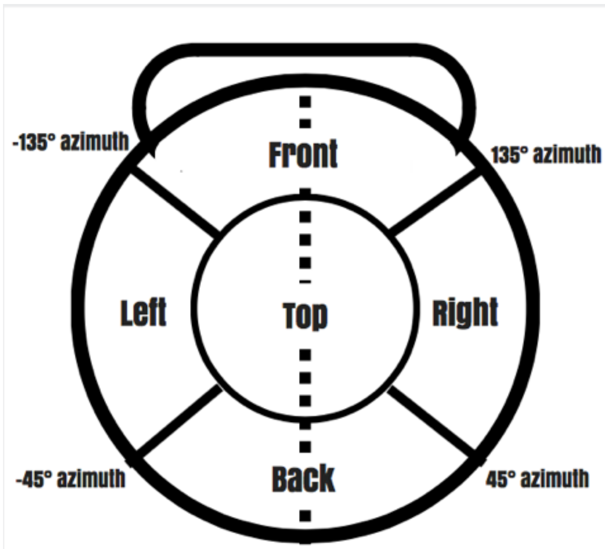

Figure 5 Impact Location

Data Analysis

The data collected in this research was analyzed using Statistical Package for the Social Sciences (SPSS: IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY). All descriptive statistics are presented as medians with [interquartile range]. The independent variables of interest include player position by group (offensive line, offensive skill, defensive line, and defensive skill) and impact location on the helmet (back, front, left side, right side, and top). The dependent variables are impact frequency, peak linear acceleration and peak rotational acceleration. The first and second research hypotheses were examined through a Chi-Square Goodness of Fit test. Hypotheses 3, 4, 5, and 6 was examined using a Kruskal-Wallis nonparametric technique. In the event that the omnibus Kruskal Wallis test is significant, a series of Mann Whitney U pairwise comparisons was used to determine group differences. Hypothesis 7 was examined through a cross tabulation of location and player position while applying the Pearson Chi Square technique. Follow-up tests examined the adjusted residuals to determine which position and impact location received a significantly different number of impacts than expected. The standardized residual and adjusted residuals can be found using the following equations:

$$\text{Std. Residual} = (O - E) / \sqrt{E} \qquad 1.1$$

$$\text{Adj. Residual} = \frac{(O-E)}{\sqrt{E*\left(1-\frac{RowMarginal}{n}\right)*\left(1-\frac{ColumnMarginal}{n}\right)}} \qquad 1.2$$ [26]

Standardized mean differences was used to report effect sizes. Type I error rate was set *a priori* at 0.05 for all statistical analyses. For the Mann Whitney U pairwise comparisons, the alpha levels were Bonferroni corrected through the equation:

$$\alpha = \frac{0.05}{\#\ follow\text{-}up\ tests}. \qquad 1.3$$

CHAPTER 4: RESULTS

Data Screening

10,850 impacts were recorded from the 2016-2017 season (practice and games); however, due to the signaling issues seen during games, all game day data (2295 impacts, 21.2%) was removed from analysis. Graphical examination of the practice data (8,555 impacts) indicated a right skewed distribution. The skewness of the peak linear acceleration graph was 2.253 with a kurtosis value of 8.002, while the peak rotational acceleration graph had a skewness value of 2.209 with a kurtosis of 10.13. Since the data was skewed to the right, the median was the measure of central tendency and the interquartile range was estimate the variability because these values are less sensitive to non-normality than the mean.

Head Impact Exposure

Examples of the frequency of impacts for individual players can be seen in Appendix D and E. These images include the magnitude and location of each impact sustained which resulted in a linear acceleration which was greater than 10 g. Irrespective of location or player position, the median linear acceleration for all seasonal practice impacts (8,555) was 23.3 [16.4-36.1] g and the median rotational acceleration value was 1047.2 [693.3-1547.8] rad/ s^2. Median linear and rotational acceleration values based on impact location and player position are reported in Tables 1 and 2.

Table 1. Median [IQR] peak linear and rotational acceleration based on impact location

IMPACT LOCATION	LINEAR ACCELERATION (G)	ROTATIONAL ACCELERATION (RAD/S^2)
BACK	21.7 [16.20-33.60]	1107.9 [790.66-1642.18]
FRONT	24.4 [16.40-36.75]	1224.3 [845.04-1769.71]
LEFT	19.7 [14.90-27.70]	978.4 [738.55-1383.47]
RIGHT	18.9 [14.88-27.20]	943.6 [696.42-1352.45]
TOP	29.7 [19.80-47.70]	613.4 [350.86-1075.45]

Table 2. Median [IQR] peak linear and rotational acceleration based on player position

PLAYER POSITION	LINEAR ACCELERATION (G)	ROTATIONAL ACCELERATION (RAD/S^2)
OFFENSIVE LINE	24.8 [17.10-36.60]	1113.1 [727.84- 1607.03]
OFFENSIVE SKILL	22.6 [15.40-35.63]	1032.7 [600.53- 1647.15]
DEFENSIVE LINE	24.6 [16.90- 38.70]	1033.2 [703.46-1517.72]
DEFENSIVE SKILL	21.8 [16.10-34.20]	1038.7 [687.88-2215.42]

A Chi Square goodness of fit test showed that impacts were not equally distributed across all five helmet locations. There was a significant difference across these locations, χ^2 (4, N=8555) = 2710.886, *p= 0.001*. Based on the standardized residuals in Table 3, more impacts were sustained at the front and back of the helmet, and significantly less impacts occurred to the left and right sides of the helmet than expected. A positive or negative standardized residual indicated significantly more or less impacts than expected respectively. A standardized residual value of 3 or greater indicates a significant difference, because this critical value approximately relates to the alpha level of 0.05.[26] Therefore, anything more or less would translate to a difference in impact frequency when compared to expected values.

Table 3. Observed, expected, and residual values by impact location

IMPACT LOCATION	OBSERVED N	EXPECTED N	STD RESIDUALS
BACK	2351	1711.0	15.47*
FRONT	3197	1711.0	35.92*
LEFT	686	1711.0	-24.78*
RIGHT	734	1711.0	-23.62*
TOP	1587	1711.0	-3.0*

** indicates significant difference from expected*

A Chi Square goodness of fit indicated that impacts were not equally distributed across player positions. A significant difference was found across position, χ^2 (3, N=8555) = 1962.444, p= 0.001. As shown in Table 4, statistically more impacts occurred to the defensive skill and line players, while significantly less impacts were sustained to the offensive line and skill players. As indicated in the table above, the sign of the standardized residuals indicate if more or less impacts occurred.

Table 4. Observed, expected, and residual values by player position

PLAYER POSITION	EXPECTED N	OBSERVED N	STD RESIDUALS
OFFENSIVE LINE	1363	2138.8	-16.78*
OFFENSIVE SKILL	942	2138.8	-25.88*
DEFENSIVE LINE	2795	2138.8	14.19*
DEFENSIVE SKILL	3455	2138.8	28.46*

** indicates significant difference from expected*

A crosstab analysis of player position and impact location found a significant relationship between these variables, χ^2 = 306.915 (12) p=0.001. Figure 6 illustrates the frequency of impacts between the impact location and player position. Across all player positions, more impacts occurred to the front of the helmet. Table 5 shows the adjusted residuals which designates where the statistical differences were. Appendix C shows the full crosstab analysis which supports the Chi Square value given.

Figure 6. Number of impacts based on player position and impact location.

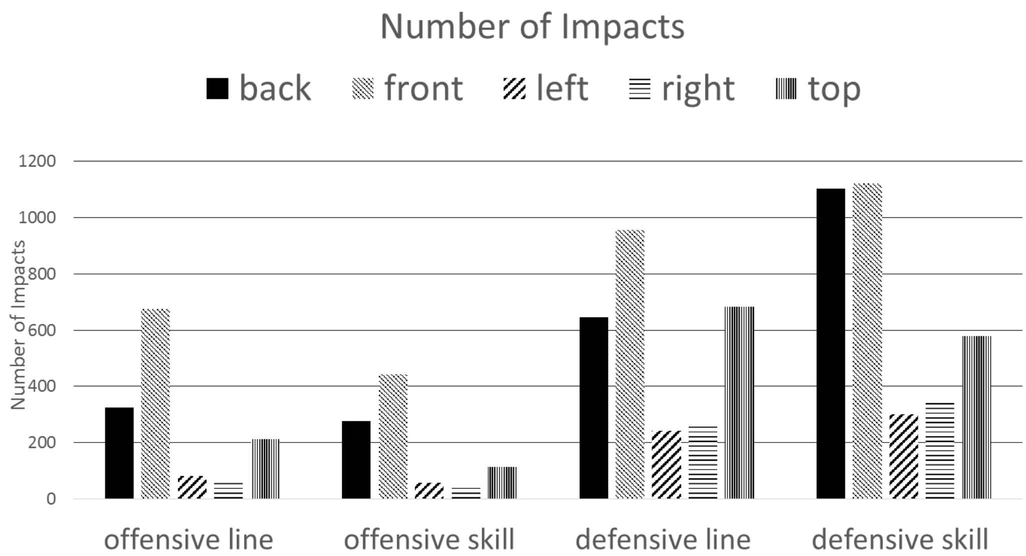

Table 5. Expected and actual impact count

		Player Position			
		offensive line	offensive skill	defensive line	defensive skill
Location					
Back	Count	326.0	277.0	646.0	1102.0
	Expected Count	374.6	258.9	768.1	949.5
	Adjusted Residual	-3.2*	1.4	-6.3*	7.5*
Front	Count	675.0	444.0	956.0	1122.0
	Expected Count	509.4	352.0	1044.5	1291.1
	Adjusted Residual	10.1*	6.6*	-4.2*	-7.7*
Left	Count	82.0	59.0	243.0	302.0
	Expected Count	109.3	75.5	224.1	277.0
	Adjusted Residual	-3.0*	-2.1	1.6	2.0
Right	Count	66.0	49.0	268.0	351.0
	Expected Count	116.9	80.8	239.8	296.4
	Adjusted Residual	-5.4*	-3.9*	2.3	4.3*
Top	Count	214.0	113.0	682.0	578.0
	Expected Count	252.8	174.7	518.5	640.9
	Adjusted Residual	-3.0*	-5.5*	9.7*	-3.6*

* indicates significant difference from expected values

Impact Location Difference

A Kruskal Wallis analysis of variance (ANOVA) revealed there was a significant difference between impact locations and linear acceleration [χ^2 (4, N=8555) = 388.822,*p*= 0.001]. Follow up Mann Whitney U tests were done between each impact location to detect within group differences, with an alpha level of α=0.005. The results can be seen in Table 6. A significant difference was found between almost all impact locations, no difference was seen between the right and left sides.

Table 6. Difference between impact locations- linear acceleration

Comparison	N	Z	*P*
Front and back	5548	−3.847	0.001
Back and left	3037	−5.863	0.001
Back and right	3085	−7.023	0.001
Back and top	3938	−13.096	0.001
Front and left	3883	−8.576	0.001
Front and right	3931	−9.7500	0.001
Front and top	4784	−10.853	0.001
Left and top	2273	−14.787	0.001
Right and top	2321	−15.965	0.001
Right and left	1420	-0.824	0.420

A Kruskal Wallis analysis of variance (ANOVA) revealed significant difference between impact location and rotational acceleration, χ^2 = 934.509, *p*= 0.001.Mann Whitney U follow up tests were performed to show group difference. Significant differences can be seen in Table 7, with an alpha level of α=0.005. No significant difference was found between the left and right side (*P*= 0.190).

Table 7. Difference between impact locations- rotational acceleration

Comparison	N	Z	P
Front and back	5548	−4.314	0.001
Back and left	3037	−5.164	0.001
Back and right	3085	−6.781	0.001
Back and top	3938	−24.883	0.001
Front and left	3883	−8.302	0.001
Front and right	3931	−10.016	0.001
Front and top	4784	−27.870	0.001

Left and top	2273	−14.327	0.001
Right and top	2321	−13.310	0.001
Right and left	1420	-1.311	0.190

Impacts to the top of the helmet sustained significantly higher linear acceleration values (29.7g) than any other location, followed by the front of the helmet (24.4g). The front of the helmet sustained significantly higher rotational accelerations (1224.25rad/s^2) than any other location, followed by the back of the helmet (1107.85rad/s^2).

Player Position Difference

A Kruskal Wallis analysis of variance (ANOVA) showed there is a significant difference between player positions and linear acceleration, χ^2 (3, N=8555) = 49.720, $p<0.05$ (P= 0.001). Mann Whitney U follow up tests found significant differences between certain positions with an alpha value of α=0.008. These results can be seen in Table 8. No difference was found between offensive line and defensive line (N=4158) P=0.946 and between offensive skill and defensive skill (N=4397) P=0.961.

Table 8. Difference between player positions- linear acceleration

Comparison	N	Z	P
Offensive line and offensive skill	2305	−3.380	0.001
Offensive line and defensive line	4158	-0.068	0.946
Offensive line and defensive skill	4818	−4.961	<0.001
Offensive skill and defensive line	3737	−3.787	<0.001
Offensive skill and defensive skill	4397	-0.048	0.961
Defensive line and defensive skill	6250	-6.027	0.001

A Kruskal Wallis analysis of variance (ANOVA) reported that there was a small difference between player position and rotational acceleration, χ^2 (3, 8555) = 8.421, $p<0.05$ ($P= 0.038$). Mann Whitney U follow up tests revealed there was no significant differences between any of the groups ($P>0.008$). Offensive line sustained significantly higher rotational accelerations ($P < 0.008$) than offensive skill and defensive skill, and rotational accelerations of the defensive line were significantly higher than offensive skill and defensive skill.

CHAPTER 5: DISCUSSION

The aim of this research was to determine if there was a relation between frequency, linear acceleration, and rotational acceleration, and impact location and player position. The results of this study suggest that players sustain impacts of, on average, 23.3 [16.4-36.1] g and 1047.3 [693.3-1547.8] rad/s^2. This value for linear acceleration is similar to reported values in previous studies investigating the response of football players to biomechanical forces.[4] However, players in a study done by Crisco et al.[27] sustained a mean linear acceleration of 20.5 g and 50th percentile peak rotational acceleration value of 1400 rad/s^2. The right skewness of the results was expected due to most impacts sustained valuing less than 40 g and 2000 rad/s^2 respectively.

Head Impact Exposure

Our results were similar to studies done by Mihalik et al.[4] and Broglio et al.[3] which reported significantly more impacts were sustained at the front and back compared to other locations on the helmet. However, these results differed from hypothesis one which was set based on preliminary data from the system. Statistically more impacts occurred to the defensive line and defensive skill than expected, which correlates to the findings of Broglio et al.[3] and Crisco et al.[27] which both had defensive line players sustaining a significantly more impacts. This differs from our hypothesis which was set based on the results of Mihalik et al.[4] that found offensive line sustained more impacts.

Impact Location

Linear acceleration at the top of the head was significantly higher than any other location which agrees with the hypothesis set at the beginning of this study that was based on studies done by Mihalik et al.[4], Broglio et al.[3], and Crisco et al.[27]. The front of the helmet sustained higher rotational acceleration values as expected based on the results from a study done by Broglio et al.[3]. Few articles studied the relationship between rotational acceleration and player position and impact location.

Player Position

Offensive line and defensive line players sustained significantly higher linear acceleration impacts than the skill players; however, no statistical difference was found between the two line groups. This did not follow what was expected based on the results of Broglio et al.[3] with one difference being that defensive line players had similar values to offensive skill with the line players being significantly higher than offensive line and defensive skill. These results align with Mihalik et al.[4] which found that offensive line players sustained significantly higher linear accelerations than any other position. The defensive and offensive line players were found to have slightly higher rotational acceleration values, but no between group differences were found with the follow up test. Broglio et al.[3] also found defensive linemen to have the highest rotational acceleration. Future tests, which study collegiate players and their rotational accelerations must be done for more accurate comparisons and conclusions to be drawn.

While Broglio et al.[3] served as a design model for this study, these results cannot truly be compared to those found by Broglio due to the fact that Broglio et al. studied high school players, and our sample was comprised of collegiate players. However, since the methods were similar, comparisons are worth noting. It is also interesting to note that some of our findings correlated to the results of Broglio[3],despite the difference in sample population. While the sample sizes of Mihalik et al. and Crisco et al.'s studies were substantially larger than the sample of this research, the participants of these studies were collegiate players. This research also discovered that there was a significant relation between player position and impact location in terms of frequency of impacts. This finding could indicate a need for different tackling techniques for specific positions. For example, since the defensive players in this study sustained significantly impacts to the top of the helmet, it could be beneficial to look at improving tackling techniques for the defense. This could lead to fewer impacts being sustained at the top of the helmet, and decreasing the player's risk for life threatening injuries.

Since the results of this research were similar to previous studies done in this field, they can be related back to the population of collegiate football players. The highest linear acceleration values found occurred at the top of the head, so serious consideration should be taken when teaching tackling techniques given what is known about the dangers of spearing. Despite the work of Heck et al.[28] back in 2004 which recommended more education on the implications of spearing and more time spent on correct tackling techniques, impacts are still being sustained at the top of the head. These impacts are resulting in the highest linear acceleration, which is an alarming statistic. It would be beneficial to evaluate teaching techniques of collegiate players and educational tools provided to the coaching staff to determine where improvements could be made. However, all of the educational tools that have been provided and regulations that are in place do not seem to be as effective as one may hope.

An additional future study could look at comparing the results to different expected results based on values from the literature. In this study, the expected results were set to be equally distributed across either all impact locations or player positions. However, since the literature has not found this to be what should be "expected", it could be beneficial to compare future results to values reported in the literature. This would add another layer of validation, and solidify where the field can improve to increase player safety.

As to be expected, we ran into some problems when completing this research. The limitations of this study primarily involved signaling issues with the Sideline Response System. Signaling issues within the stadium and away games limited the recording of impacts. This led to 2,295 impacts removed from our sample before analysis. Further research should be done at the collegiate level to determine the effect that participation type has on impact biomechanics. The results of this and previous studies are alarming; these values are extremely high for only occurring in practice. It makes one wonder why these potentially dangerous impacts are being encouraged in practice. While we can loosely relate our findings to the larger population of collegiate players, the main use of these findings can be to educate the players and coaches at this university about areas of concern that are seen through these results.

The distribution of players in this study was not even across all four groups. There were more skill players than line players. In this study, defensive skill players sustained significantly more impacts than expected; however, offensive skill players sustained significantly less impacts than expected. A follow up study should be done with an equal number of players from each position to determine if the number of players had any influence on the results. There is still little research done on rotational acceleration, so it is difficult to determine the accuracy of these findings. Despite the unequal distribution in the number of participants, significantly more impacts are being sustained by the defensive players. It is also interesting to note that the line players sustained impacts which resulted in high linear acceleration. This could indicate that these players are using their helmets almost as a weapon with more force behind it since there is a short distance they have to move before impacting an opposing player.

The impacts in this study were not validated against any game or practice film. Therefore, it must be noted that some of the recorded impacts may not be valid. A future study should be done with all impacts compared against film to remove any “impacts” that occurred because of outside events, i.e. a playing throwing the helmet on the ground during practice.

APPENDIX A. IRB APPROVAL LETTER

THE UNIVERSITY OF SOUTHERN MISSISSIPPI

INSTITUTIONAL REVIEW BOARD
118 College Drive #5147 | Hattiesburg, MS 39406-0001
Phone: 601.266.5997 | Fax: 601.266.4377 | www.usm.edu/research/institutional.review.board

NOTICE OF COMMITTEE ACTION

The project has been reviewed by The University of Southern Mississippi Institutional Review Board in accordance with Federal Drug Administration regulations (21 CFR 26, 111), Department of Health and Human Services (45 CFR Part 46), and university guidelines to ensure adherence to the following criteria:

- The risks to subjects are minimized.
- The risks to subjects are reasonable in relation to the anticipated benefits.
- The selection of subjects is equitable.
- Informed consent is adequate and appropriately documented.
- Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
- Appropriate additional safeguards have been included to protect vulnerable subjects.
- Any unanticipated, serious, or continuing problems encountered regarding risks to subjects must be reported immediately, but not later than 10 days following the event. This should be reported to the IRB Office via the "Adverse Effect Report Form".
- If approved, the maximum period of approval is limited to twelve months. Projects that exceed this period must submit an application for renewal or

continuation.

PROTOCOL NUMBER: 16082202

PROJECT TITLE: Correlational Analysis of Descriptive Biomechanics in American Football

PROJECT TYPE: New Project

RESEARCHER(S): Samantha Eshleman

COLLEGE/DIVISION: College of Health

DEPARTMENT: Kinesiology

FUNDING AGENCY/SPONSOR: N/A

IRB COMMITTEE ACTION: Expedited Review

Approval PERIOD OF APPROVAL: 08/25/2016 to

08/24/2017

Lawrence A. Hosman, Ph.D.
Institutional Review Board

APPENDIX B. IRB MODIFICATION LETTER

THE UNIVERSITY OF SOUTHERN MISSISSIPPI

INSTITUTIONAL REVIEW BOARD
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NOTICE OF COMMITTEE ACTION

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- The risks to subjects are minimized.
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- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
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- If approved, the maximum period of approval is limited to twelve months. Projects that exceed this period must submit an application for renewal or

continuation.

PROTOCOL NUMBER: CH16082202

PROJECT TITLE: Correlational Analysis of Descriptive Biomechanics in American Football

PROJECT TYPE: Change to a Previously Approved Project

RESEARCHER(S): Samantha Eshleman

COLLEGE/DIVISION: College of Health

DEPARTMENT: Kinesiology

FUNDING AGENCY/SPONSOR: N/A

IRB COMMITTEE ACTION: Expedited Review

Approval PERIOD OF APPROVAL: 08/25/2016 to

08/24/2017

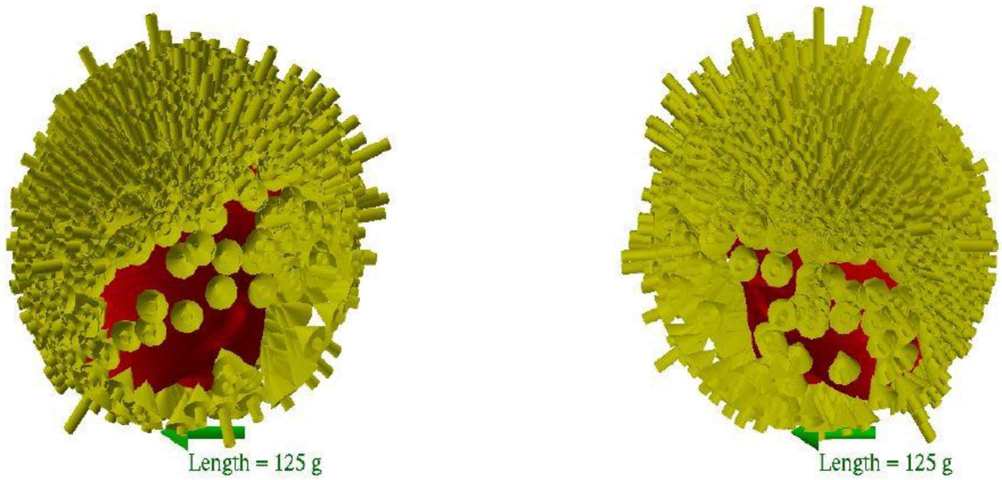
Lawrence A. Hosman, Ph.D.
Institutional Review Board

APPENDIX C. CROSSTABULATION OF LOCATION AND PLAYER POSITION

			Re_NewPosOldPos				
			Offensive Line	Offensive Skill	Defensive Line	Defensive Skill	Total
Re_Location	Back	Count	326	277	646	1102	2351
		Expected Count	374.6	258.9	768.1	949.5	2351.0
		Residual	-48.6	18.1	-122.1	152.5	
		Standardized Residual	-2.5	1.1	-4.4	5.0	
		Adjusted Residual	-3.2	1.4	-6.3	7.5	
	Front	Count	675	444	956	1122	3197
		Expected Count	509.4	352.0	1044.5	1291.1	3197.0
		Residual	165.6	92.0	-88.5	-169.1	
		Standardized Residual	7.3	4.9	-2.7	-4.7	
		Adjusted Residual	10.1	6.6	-4.2	-7.7	
	Left	Count	82	59	243	302	686
		Expected Count	109.3	75.5	224.1	277.0	686.0
		Residual	-27.3	-16.5	18.9	25.0	
		Standardized Residual	-2.6	-1.9	1.3	1.5	
		Adjusted Residual	-3.0	-2.1	1.6	2.0	
	Right	Count	66	49	268	351	734
		Expected Count	116.9	80.8	239.8	296.4	734.0
		Residual	-50.9	-31.8	28.2	54.6	
		Standardized Residual	-4.7	-3.5	1.8	3.2	
		Adjusted Residual	-5.4	-3.9	2.3	4.3	
	Top	Count	214	113	682	578	1587
		Expected Count	252.8	174.7	518.5	640.9	1587.0
		Residual	-38.8	-61.7	163.5	-62.9	
		Standardized Residual	-2.4	-4.7	7.2	-2.5	
		Adjusted Residual	-3.0	-5.5	9.7	-3.6	
Total		Count	1363	942	2795	3455	8555
		Expected Count	1363.0	942.0	2795.0	3455.0	8555.0

APPENDIX D. PLAYER REPORT- PLAYER WITH MOST IMPACTS (OVER 10 G)

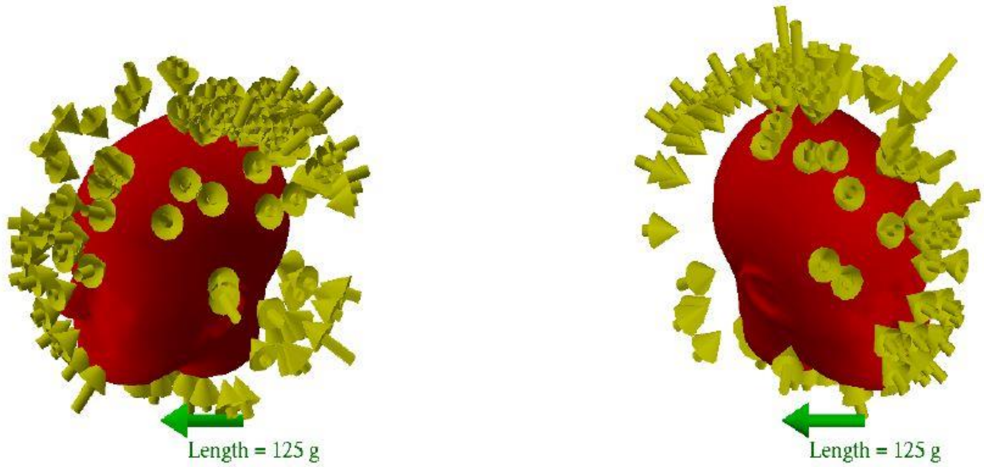
6. Summary of Impact Magnitude and Location for Impacts Above Threshold



All valid impacts sustained during the requested date range. The length of the arrow represents the magnitude of linear acceleration (g)

APPENDIX E. PLAYER REPORT- IMPACTS OVER 10 G.

6. Summary of Impact Magnitude and Location for Impacts Above Threshold



All valid impacts sustained during the requested date range. The length of the arrow represents the magnitude of linear acceleration (g)

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